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PSYCHOLOGICAL PERFORMANCE DURING SLEEP LOSS AND CONTINUOUS MENTAL WORK: THE EFFECTS OF INTERJECTED NAPS

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The need for research and recommendations about sleep logistics planning in sustained operations environments is discussed. The nap literature is reviewed and problems in experimental methodology, cross-study comparability, and generality are noted. To address these problems, a research programme has been initiated in which subjects assume the role of command-post operations officers in conditions anticipated for the sustained-intensive battlefield. The results of experiments from this programme indicate that continuous, intensive mental work combined with 2-3 days of sleep loss leads to greater performance decrements than those found in studies not emphasizing continuous cognitive demands. While the role of various countermeasures, including the effects of physical fitness, physical exercise and cognitive workload have been investigated, none of these interventions reduced the impairment in performance found in this scenario. Two experiments, however, are reported which examine the ameliorative effects of short naps on performance. In the first, a 2-hour nap was taken after about 40 hours of wakefulness from 2200h-2400h. This nap served to <u>maintain</u> performance; the 25-30% pre- to post-midnight downturn in performance typically observed in our continuous work studies was prevented. In a further experiment, a 2-hour nap was taken after about 46 hours of wakefulness from 0400h-0600h. This nap served to <u>recuperate</u> performance; the expected post-midnight degradation occurred, but following the nap performance returned to the pre-midnight level. The results are discussed in terms of new strategies for maintaining performance capability during extended work schedules.

1 INTRODUCTION

Advances in military technology (including improved night vision devices, high performance vehicles, advanced communications systems, and increased firepower) and resultant changes in doctrine (emphasizing around-the-clock capabilities) dictate that future conflicts will be high-intensity sustained operations (SUSOPs) lasting several days to weeks. Since NATO forces are not able to significantly increase manpower, combatants will, at times, have to perform at intense levels for extended periods. Soldiers will be expected to work with minimal, or no, sleep. Rest will be dictated by the nature of the battle and will be fragmentary at best. Even when allowed to sleep, combatants will be expected to awaken quickly and rejoin the fighting immediately. It is imperative that high levels of performance efficiency are maintained under these severe conditions.

Many experimental studies have shown that during one or more nights without sleep, as well as over longer periods of reduced or fragmented sleep, decrements occur in mood and cognitive performance (for reviews see Wilkinson, 1965, 1969a, 1969b; Naitoh & Townsend, 1970; Johnson & Naitoh, 1974; Naitoh, 1976; Kjellberg, 1977; Johnson, 1979; NATO AHSG, 1981; Angus & Heslegrave, 1983). Due largely to these detrimental effects of sleep loss, the single most important limitation to sustained operations, is therefore the human (DRG Seminar, 1983, p. 559).

The operational consequences of sleep deprivation have long been recognized (Marshall, 1962). In fact, Naitoh (1983) has argued that adequate planning for sleep is as important as logistics for transportation,

equipment, ammunition and food. Sleep logistics planning is difficult, however. Work/rest schedules based on orderly civilian patterns are not appropriate for sustained operations, especially in the absence of replacements. Consequently,

> Lack of concern with sleep logistics has resulted in a reduction in the number of effective combat personnel during SUSOPs because of continual fatigue, constant sleepiness, deteriorated mood, lowered motivation and degraded task performance (Naitoh, 1983, pp. 114-115).

Barring the development of chemical aids to intensify sleep or to reduce its need, one of the most important aspects of maintaining human effectiveness on the battlefield is the provision of periods for nap sleep. The present paper reviews the nap literature and outlines methodological difficulties in the research. We then describe a research paradigm designed to overcome some of these problems and apply our methodology to the assessment of sleep loss countermeasures. Finally, we discuss the results in terms of new strategies for maintaining performance during extended work schedules.

2 NAP COUNTERMEASURES

The general consensus among researchers regarding human capabilities under sleep loss seems to be that "...even small amounts of sleep are beneficial" (e.g., Haslam, 1981, p. 457). However, these beneficial effects are influenced by a number of factors including nap duration, circadian placement, and the amount of prior sleep loss. (In this paper a "nap" refers to a "short recovery sleep" and not to sleep taken in addition to normal nocturnal sleep.) Because only fragmentary rest episodes will be available during sustained operations, it is important to be able to specify both the minimal amounts, and the optimal temporal placement, of sleep required for maintaining or recovering effective performance.

2.1 Nap Duration

Some suggestions regarding minimal amounts of required sleep come from the partial sleep deprivation literature (cf. Wilkinson, Edwards, & Haines, 1966; Wilkinson 1969b; Hamilton, Wilkinson, & Edwards, 1972; Taub & Berger, 1973; Tilley & Wilkinson 1984). These studies are primarily concerned with determining how little sleep is required to maintain normal performance levels. Generally, 3-4 hours of sleep are needed during the first night of reduced sleep to maintain performance; during the second night, at least 5 hours are required (it does not seem to matter when the sleep is taken -- anytime between 2300h and 0800h appears to be effective).

Other studies have been concerned with investigating the minimal amounts of sleep required to improve performance over no-sleep conditions. A recent study by Webb (1987) showed that naps of only 2 hours duration are beneficial compared to no-sleep controls. Studies have also investigated the impact of distributed short sleeps and have found that the minimal times required for beneficial performance effects are similar to those suggested by the results of the partial sleep loss studies. For example, Lubin, Hord, Tracy and Johnson (1976) found that when experimental subjects were given five 1-hour naps each day for 2 days, they showed fewer decrements in performance compared to control subjects who underwent total sleep loss.

Some studies have directly investigated whether these minimal suggested amounts of sleep are more beneficial when taken as multiple short sleeps (distributed naps) or as longer continuous naps. Mullaney, Kripke, Fleck and Johnson (1983) allowed one group of subjects three 1-hour sleep periods each day for two days. The nap subjects performed better than subjects who were completely sleep deprived, but not as well as those who received the same amount of sleep (6 hours) in a continuous block. The subjects in Hartley's (1974) experiment received three 80-minute naps spread over a 12-hour period between midnight and noon. Although this group did not perform as well as a group receiving a normal 8-hour sleep, they performed better than a group that received a continuous 4-hour sleep between 0100h and 0500h. These results are in contrast to those of Mullaney et al. (1983). However, the better performance by the distributed-nap group compared to the continuous-nap group may be accounted for by differentially more hours of wakefulness prior to testing for the continuous-nap group. Since subjects in this study were

tested only once per day at 2100h, the 4-hour nap group may have performed relatively poorly because they had a 16-hour period of sustained wakefulness before testing while the group receiving distributed sleep had only 8 hours of wakefulness before testing. Using more stringent testing criteria, Haslam (1985) compared the performance of a group who slept for one hour in every six hours beginning at 0500h with a group receiving a continuous 4-hour nap from 0200h-0600h. Cognitive tests were administered at 1000h and 0100h. There were no significant differences in the performance of the two groups.

To summarize, both single and multiple naps within 24-hour periods reverse disruptions on performance and mood related to sleep loss. Longer naps usually have greater benefits in terms of mood, performance and alertness (Rutenfranz, Aschoff, & Mann 1972; Morgan, Brown, & Alluisi, 1974; Opstad, Ekanger, Nummestad, & Rabb, 1978; Haslam, 1981; Lumley, Roehrs, Zorick, Lamphere, & Roth, 1986), but it is not yet clear whether single versus multiple naps have differential ameliorative impacts on performance degradation.

2.2 Nap Placement

Nap placement in the circadian cycle may be as important as nap duration in determining the effectiveness of short recovery sleep. As the research is reviewed, however, it will be seen that methodological differences severely complicate determining when naps are most beneficial.

On the basis of some studies, it might be concluded that circadian placement has important effects, with early morning naps possessing poorer recuperative potential. Naitoh (1981) showed that a 2-hour nap taken after 45 hours of wakefulness and at the circadian nadir (0400h-0600h) had little recuperative value compared to a 2-hour nap taken after 53 hours of wakefulness during the rising phase of the cycle (1200h-1400h). The lack of restoration following a 2-hour nap taken at the nadir might be explained in terms of "sleep inertia" since these subjects showed deteriorated ratings of fatigue, mood, sleepiness and arousal compared to a control group that did not nap. In a subsequent study, Englund, Naitoh, Ryman and Hodgdon (1985) also found that a 3-hour nap in the nadir had little benefit in improving performance.

On the other hand, several studies have not found differential performance effects as a function of the circadian placement of naps (Taub, 1979; Gillberg, 1984; Dinges, Orne, & Orne, 1985; Webb, 1985). For example, Gillberg (1984) found no difference in morning performance between groups provided with 1-hour naps at either 2100h or 0430h. These results may have been affected by differences in time from waking to testing between the two conditions. Similar data were obtained by Webb (1987) on an addition task. Although the morning (0800h-1000h) and evening (2200h-2400h) sleep periods were confounded with different circadian testing times, both naps resulted in performance increments. Importantly, there was no difference between the conditions when testing was done in the circadian trough (between 0100h-0500h).

In a study assessing performance upon awakening, Dinges et al. (1985) found both differential effects and no effects of circadian placement. During a three-day period of "quasi continuous work", each of five groups had a 2-hour nap but with differing amounts of prior wakefulness. Naps were taken at either of two times of day: "peak" naps were at 1500h-1700h, and "trough" naps were from 0300h-0500h (i.e., similar to Naitoh's nadir naps). The results suggested that the differential effects of circadian placement may depend on the type of task used. While the results of a subtraction task led the authors to suggest that trough naps produced greater cognitive deficits than peak naps, no significant differences were found between the trough and peak naps with respect to a reaction time task (answering a telephone immediately upon wakeup). However, the difference may have also been influenced by testing time since the subtraction task did not occur until several minutes after awakening, while the reaction time task was immediate.

In a further study, Dinges, Orne, Whitehouse and Orne (in press) replicated their finding that the circadian placement of naps (peak vs. trough) did not affect reaction time, and discovered that performance benefited most from naps taken after shorter periods of sleep loss (i.e., 6 or 18 hours after the beginning of the experiment). Given this mixture of research findings, an important question that must yet be resolved concerns the role of naps in recuperating performance degraded by sleep loss.

In summary, there are several factors which should be considered in nap placement. These factors include the circadian position of the nap, the time of testing relative to awakening, the type of task, and the amount of prior sleep loss. The complex interplay of these factors in determining the ameliorative influence of naps is not clearly understood; only general trends exist relating nap duration, time of day and prior wakefulness. The major problem in determining the benefits of nap sleep is methodological; differences in experimental designs and conditions do not allow for direct comparisons across studies. Moreover, results may differ as a function of what tasks and performance measures are used, as well as how they are administered (e.g., if the testing is done once versus several times per day, or if testing is done during the sleep inertia period versus several hours later).

3 DCIEM RESEARCH

3.1 Background

For the future battlefield, knowledge is required concerning how well the results of laboratory experiments, like those cited above, generalize to sustained high-intensity combat operations. Are laboratory-based estimates of performance degradation and the effectiveness of countermeasures valid for battlefield conditions? For research to be operationally relevant, a more complete understanding is required of battlefield stressors and their interactions with the types of tasks to be accomplished and with individual performance capabilities.

Very little scientific research bears directly on the interaction of environmental/situational and individual stressors (cf. Johnson, 1982), especially for wartime environments (NATO AHSG, 1981, p. 56). Studies attempting to estimate performance degradations for sustained operations have, for the most part, followed the traditional approach to the study of sleep loss. Subjects' capabilities are measured on selected tasks at various times during the periods of wakefulness (cf. Drucker, Canon, & Ware, 1969; Banks, Sternberg, Farrell, Debow, & Delhamer, 1970; Haggard, 1970; Ainsworth & Bishop, 1971; Morgan et al., 1974; Opstad et al., 1978; Banderet, Stokes, Francesconi, Kowal, & Naitoh, 1981; Haslam, 1981, 1982; Naitoh, 1981; Naitoh, Englund, & Ryman, 1982). This approach engenders several major methodological difficulties.

First, performance tasks are often not representative of operational tasks. Because performance degradation is highly dependent upon the types of tasks to be performed (Wilkinson & Stretton, 1971), the selection of appropriate tasks with a high degree of generality to the battlefield is imperative for accurate assessments of the expected degradations. For example, while performance on simple vigilance tasks requiring sustained attention may be impaired following partial sleep deprivation (Wilkinson et al., 1966), performance on interesting tasks often shows no visible impairment for up to 42 hours without sleep (Wilkinson, 1964). Similarly, the use of nonrepresentative tasks may lead to underestimates of the deleterious performance effects of sustained operations.

Second, laboratory tests may not be administered with sufficient frequency to afford reliable information regarding performance efficiency. Intermittent testing, that is, administration varying from every hour or two (e.g., Alluisi, 1969; Morgan et al., 1974) to only once per day (e.g., Opstad et al., 1978; Haslam, 1981) may not produce sufficient data to obtain reliable estimates of performance. These data may also be confounded by circadian variations, with performance being best during the day and worst at night, particularly between 0200h and 0600h (Colquhoun, Blake, & Edwards, 1968; Hockey & Colquhoun, 1972). Additionally, if subjects are tested infrequently, they may be able to draw on unused reserves or capacity not required during interim periods to enhance performance during test periods. Thus, performance estimates based on intermittent testing may be overestimates based on short term high-energy expenditure because non-demanding inter-test-intervals may attenuate the general drain on energy reserves (Harris & O'Hanlon, 1972; Morgan et al., 1974; Naitoh, 1976; Johnson, 1979).

A third problem is that different tests are differentially sensitive to sleep loss. To illustrate, some studies of partial sleep deprivation (e.g., Webb & Agnew, 1965, 1974; Rutenfranz et al., 1972; Friedmann, Globus, Huntley, Mullaney, Naitoh, & Johnson, 1977) have shown no performance decrements as a result of reduced sleep. As pointed out by Tilley and Wilkinson (1984), this may have been due to the use of

insensitive performance tests. Another complicating factor is that the duration of a test will affect its sensitivity. For instance, short tests are often less sensitive to performance changes than longer versions of the same tests. While the loss of one complete night of sleep typically has no effect on the first five minutes of work for most kinds of tests, there is clear impairment when tests are prolonged from 15 to 45 minutes (Wilkinson, 1961, 1965).

Finally, even if testing is representative, frequent and uses sensitive tasks of sufficient duration, if it is low in demand (intensity) estimates of performance impairment may be conservative and may be invalid for high-demand sustained operations.

Because many of the studies estimating performance degradation for sustained operations included a mixture of more or less sensitive cognitive tasks, intermittent testing, and non-demanding inter-test-intervals, their estimates of expected performance degradation may be conservative. Studies providing the best estimates are likely those where the environmental demands were more continuous (e.g., Morgan et al., 1974; Naitoh, 1981; Naitoh, Englund & Ryman, 1982). Even those studies, however, contain lengthy periods of inactivity, or time devoted to tasks of low cognitive demand.

Closest to the ideal of continuous environmental demands is the study by Mullaney et al. (1983) in which subjects were required to work at four tasks that were repeated every 10 minutes for 42 hours. Serious decrements in performance and disturbing psychological events (e.g., visual illusions, hallucinations, derealizations and disorientations) began after about 18 hours of testing (about 2300h). This is earlier than has generally been reported in sleep-loss studies (cf. Johnson & Naitoh, 1974). However, these results may be limited in how well they generalize to high-intensity sustained operations conditions because the tasks were repeated every 10 minutes. This repetition likely potentiated the monotony of the situation resulting in enhanced the sleep loss effects (Wilkinson, 1965).

DCIEM's sustained operations research programme has been designed to address some of the above limitations. It is primarily concerned with estimating the effects of sustained mental work and sleep loss on a range of cognitive abilities related to command and control performance. In this paper the methodology will be briefly described and some early results showing the effects of continuous mental work on cognitive performance will be discussed. Then, the results from some counterdegradation studies will be presented, including the effects of physical conditioning, physical exercise, low mental workload and interjected 2-hour naps. For more specific details regarding both methodology and continuous performance results see papers by Angus and Heslegrave (1983, 1985) and Heslegrave and Angus (1983, 1985).

3.2 Experimental Environment

The environment is intended to provide a continuous high-demand battery of cognitive measures sensitive to meaningful performance, especially with regard to command and control functions. It has been developed as a brigade level command-post in which subjects assume the role of operations duty-officers. Their primary function is to monitor a communications network which involves accessing, reading, understanding, interpreting and filing message information as well as updating tactical maps. This information provides the basis for decisions the subjects are required to make as the scenario progresses. Embedded in and distributed around this "message-processing" task are a variety of cognitive tests.

The laboratory is self-contained and can accommodate personnel for extended periods. In a typical experimental run four subjects work individually in separate test rooms which are isolated from the experimenters' control area. Closed-circuit televisions are used to visually monitor the subjects, and slave monitors display the information on each subject's terminal screen. Continuous EEG, ECG and various other physiological responses are recorded on ambulatory cassette recorders. (This paper will not report physiological results.) The testing system is fully automated: a computer controls the experiment by presenting the stimuli, collecting the responses, and storing the data for later analyses.

For sustained-operations experiments each four-subject group is resident in the laboratory for five days. On their arrival the subjects are briefed on the scenario and given explanations of the military concepts and

terminology. They are given extensive training and practice on all tasks. In the evening they relax, are prepared for physiological recordings, and are allowed to sleep for an 8-hour period. Subjects are awakened between 0600h-0800h and the scenario begins approximately an hour later. After 64 hours, the subjects sleep for an 8-hour recovery period (during the same hours as the baseline sleep), and the next morning are tested for recovery effects (usually over a six hour period). Depending on the particular experiment, subjects either receive a 2-hour nap placed at a strategic circadian time or undergo total sleep deprivation. During the experiment all time-pieces are removed and interpersonal communication between subjects and laboratory staff is minimized. Transport home is provided for the subjects following the recovery period.

In most of the experiments 12-16 subjects are used. Civilian subjects have included both male and female university students. Military subjects have consisted of young enlisted men, young officers, and older (35-40 years) commissioned and noncommissioned officers.

3.3 Experimental Design

The experiments follow a general design in which several six-hour blocks of identical cognitive tasks are presented. Only the content of the military messages changes over the experiment. As an example Figure 1 illustrates the design of the study investigating the effects of a nap between 2200h-2400h, after 40 hours of sleep loss.

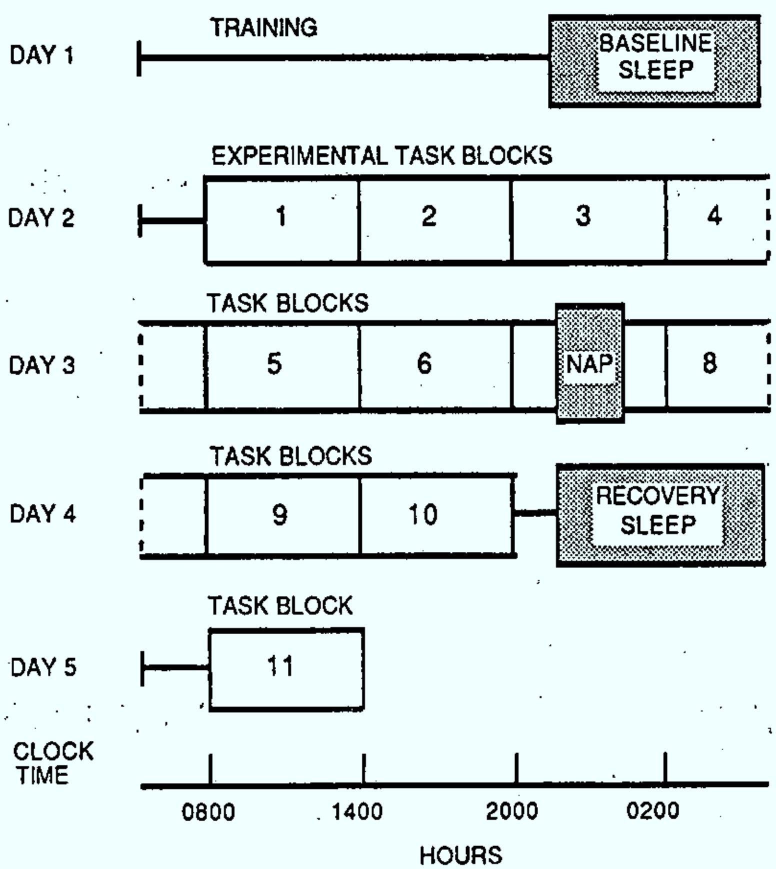

FIGURE 1. Experimental Design

Outline of design for an experiment investigating the effects of a 2-hour nap between 2200h-2400h.

The range of activities in each of the eleven task blocks is shown in Figure 2. Each subject performs the same sequence of blocks and tasks within blocks. In this experiment there were three 2-hour work sessions per block, each separated by short rest breaks. An exception is block 7 where a nap was substituted for the second work session.

FIGURE 2. Representative Task Block

Experimental activities and their temporal occurrence during a typical 6-hour task block.

6 - HOUR TASK BLOCK

START TIME (Real)	START TIME (Elapsed)	TASKS	
08:00	**00:00**	**Scales & Battery**	SESSION 1
08:15	00:15	Decode (Normal)	
08:20	00:20	Messages	
08:30	00:30	Decode (Motivated)	
08:35	00:35	Messages	
08:45	**00:45**	**Scales & Battery**	
09:00	01:00	Decode (Group)	
09:05	01:05	Syllogisms	
09:20	01:20	Messages	
09:30	01:30	Decode (Normal)	
09:35	01:35	Missile Defence	
09:40	01:40	**** Break ****	
10:00	**02:00**	**Scales & Battery**	SESSION 2
10:15	02:15	Serial	
10:25	02:25	Messages	
10:35	02:35	Subtraction	
10:40	02:40	Messages	
10:55	**02:55**	**Scales & Battery**	
11:10	03:10	Messages	
11:20	03:20	Logical Reasoning	
11:30	03:30	Missile Defence	
11:35	03:35	**** Break ****	
12:00	**04:00**	**Scales & Battery**	SESSION 3
12:25	04:15	Memory (Training)	
12:35	04:25	Messages	
12:35	04:35	Digit Span	
12:45	04:45	Messages	
12:55	**04:55**	**Scales & Battery**	
13:10	05:10	Messages	
13:20	05:20	Plotting & Memory (Recall)	
13:30	05:30	Missile Defence	
13:35	05:35	**** Break ****	

The experimental tasks range in duration from 5-15 minutes. A 15-minute "Scales & Battery" package occurs approximately once per hour at the beginning, and again halfway through, each work session. This package comprises a variety of shorter tasks (illustrated in Figure 3) which have been found to be as sensitive to sleep loss effects as longer duration tasks (Heslegrave & Angus, 1985). These short tasks are used to monitor performance hourly.

FIGURE 3. Scales & Battery Package

Order and duration of the component tasks.

SCALES AND BATTERY

SUBJECTIVE SCALES	6 minutes
SERIAL REACTION TIME	2 minutes
LOGICAL REASONING	2 minutes
SUBTRACTION	2 minutes
PLOTTING	3 minutes

3.4 Tasks

Of the many performance tasks incorporated in these experiments, a few are typically used in many sleep loss studies. These include: a variant of the four-choice Serial Reaction Time task described by Wilkinson and Houghton (1975); an Encode/Decode task similar to that reported by Haslam (1985); a continuous Subtraction task adapted from Cook, Cohen and Orne (1972); and a Logical Reasoning task devised by Baddeley (1968). Some of the tasks were slightly amended to adapt them to the military scenario. In addition, the following self-report measures were collected: the Stanford Sleepiness Scale (Hoddes,

Zarcone, Smythe, Phillips & Dement, 1973); the School of Aerospace Medicine (SAM) Subjective Fatigue Checklist (Harris, Pegram & Hartman, 1971); and the NHRC Mood Scale (Johnson & Naitoh, 1974). It was intended that the results of these "standard" measures be compared with the results of previous sustained operations experiments in order to determine the effectiveness of this continuous testing environment. For more detailed information about the tasks and comparisons with results from other studies see Angus and Heslegrave (1983, 1985) and Heslegrave and Angus (1983, 1985).

The Message Processing task provides the continuous operations context for the experiments. Subjects begin this task by monitoring two message queues of differing priority displayed on their terminal screens. They are instructed to always access messages from the priority 1 queue (if available) regardless of the number of priority 2 messages. A new message arrives about every 90 seconds, with priority 2 messages outnumbering priority 1 messages by a ratio of 8:1. The subjects' task is to read and understand each message well enough to answer a set of questions which follows. The priority 1 questions require subjects to decode the resource state of various brigade units. Priority 2 questions require subjects to perform such duties as identifying the locations of various units (using the map grid references), describing units' activities (current or intended), selecting the most appropriate unit for a specific task, calculating equipment resources, and estimating travel distances and times of arrival. Most of the questions require short phrases to be typed on the keyboard, while some require the scenario map to be up-dated. Other questions request that summaries be hand-written and manually filed. Accurate completion of the written summaries is important because previously processed messages cannot be retrieved from the computer; the manually filed information is thus necessary for answering questions asked in later messages.

3.5 Experimental Studies

The studies reported in this section established the pattern and degree of performance degradation observed during sleep loss in the continuous work paradigm. As well, the results of investigations into several countermeasures will be presented and discussed.

3.5.1 Baseline Results

The first experiment investigated the effects of 54 hours of continuous mental work and sleep on cognitive performance. Figure 4 illustrates data from the Fatigue Scale that were typical of results from the self-report measures. They are presented in terms of block (6-hour) means. As can be seen in the figure, subjects became progressively more fatigued (i.e., they had lower scores) over the experiment. However, the fatigue effect became acute about 18 hours into the experiment (about 0300h) and then plateaued for about 24 hours. Following this plateau, another dramatic decline occurred from 0300h to 0900h during the second night. The other subjective scales showed similar declines and plateaus over the 6-hour blocks.

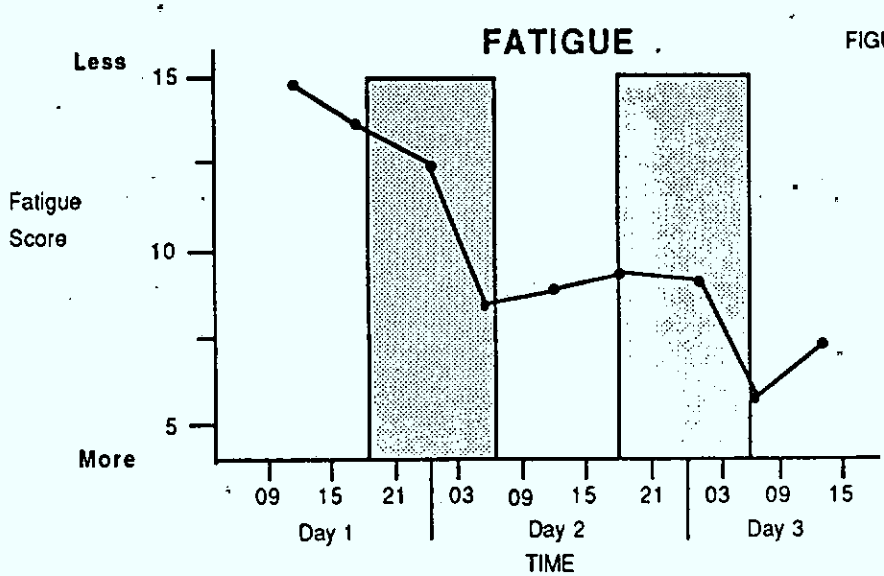

FIGURE 4. Continuous Mental Work Experiment

Each data point represents the mean of the six scores obtained in each 6-hour block of the continuous, 54-hour mental work experiment. Larger numbers on the ordinate represent less subjective fatigue.

Results from the Encode/Decode task are representative of the objective performance tasks. Data from the 10-minute version of this task were collected once in each block of the experiment. Figure 5 shows the changes in the number of correct responses and number of errors. A significant main effect over time showed that the declining number of correct responses had plateaus similar to the Fatigue scale results. Subjects maintained accuracy at the expense of speed. As can also be seen in the figure, throughout the experiment subjects made fewer correct responses and more errors on the Decoding task than on the Encoding task.

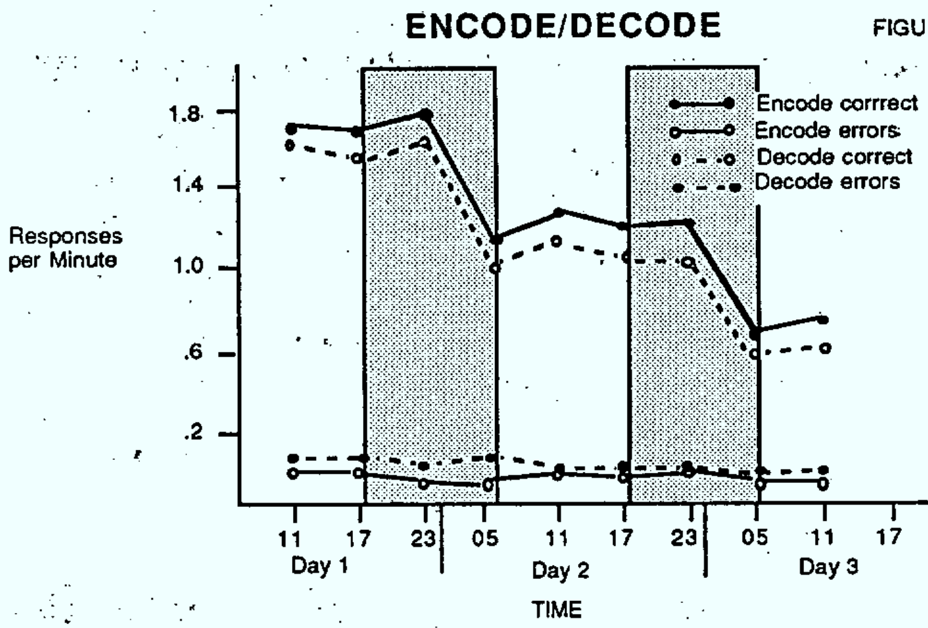

FIGURE 5. Continuous Mental Work Experiment

Mean number of correct responses and errors per minute for the 10-minute trials during each of the nine 6-hour blocks in the 54-hour continuous mental work experiment.

Data from the Message Processing task showed similar trends. Figure 6 illustrates mean processing time every three hours across the experiment. Although the messages themselves were controlled neither for length nor for the number of questions asked per message, the work required was relatively homogeneous across sessions. The results were similar to those from the other measures except that the early sessions showed an initial improvement in performance (reduced processing time) probably because the subjects were still learning strategies for dealing with the various types of message problems. Once the subjects became familiar with the task (by about 2100h of the first day), a sleep loss effect was apparent in the increased time required to process the messages. This increase plateaued until 2400h the next night, followed by a dramatic decline in performance (increase in processing time).

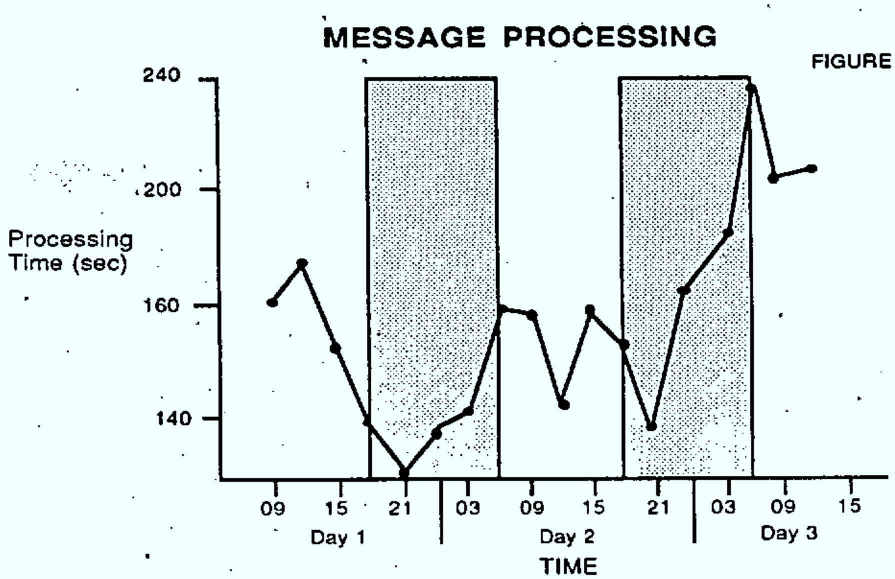

FIGURE 6. Continuous Mental Work Experiment

These data represent the amount of time subjects needed to read, understand and interpret the military messages, answer questions, and file information. The points plotted are the mean message processing times across 3-hour periods.

As noted in Section 3.1, tasks of short duration are usually not sensitive to the effects of sleep loss; subjects are able to maintain their attention for the short test period and override the effects of fatigue (Wilkinson, 1962, 1965). Figure 7 contrasts correct response data from short-duration (1-minute) and long-duration (10-minute) versions of the Reaction Time task. (Results from other short duration tasks were similar; see Heslegrave & Angus, 1985). Although the level of responding was higher for the short task, both versions showed the same topography. This demonstrates that short tasks can be as sensitive to sleep loss as longer ones, at least in high-demand cognitive work environments. Because our "short tasks" are embedded in 2-hour sessions of continuous work, they might be considered as elements of a single long heterogeneous task. This interpretation would be consistent with Wilkinson's (1969b) suggestion that tasks need to be of long duration to be sensitive to the effects of sleep deprivation.

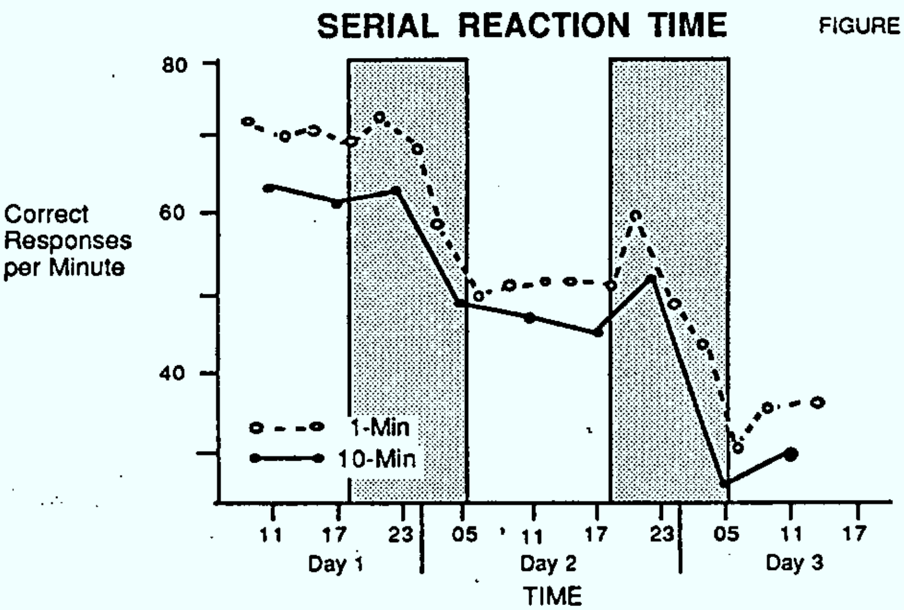

FIGURE 7. Short versus Long Task Duration

The figure contrasts the mean number of correct responses for both 1- and 10-minute versions of the reaction time task. Each point for the 10-minute task is the mean number of correct responses per minute.

Support for the notion that our long work sessions are functionally similar to long tasks is found in Figures 8 and 9. The figures present data collected at the beginning of work sessions ("After Rest") and data collected halfway through sessions ("During Work"). Figure 8 shows that performance changes significantly differently depending upon when the data are collected. Once fatigue effects began to emerge (about 2400h), the "After Rest" and "During Work" curves began to diverge and did not overlap for the remainder of the experiment.

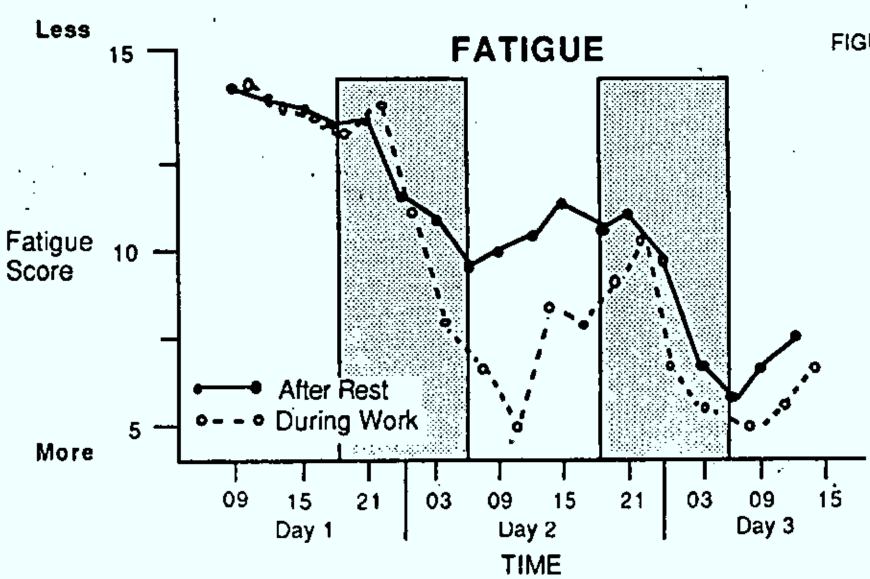

FIGURE 8. Fatigue Levels Following Rest and Work

The figure shows differential changes in the subjective level of fatigue as a function of whether subjects completed the scale following short rest breaks (solid line) or one hour of mental work (dotted line).

The other subjective scales and performance tests (e.g., Figure 9) showed similar results. In general, once the effects of sleep loss were felt, subjects were less able to override them during the work sessions than they were immediately after resting.

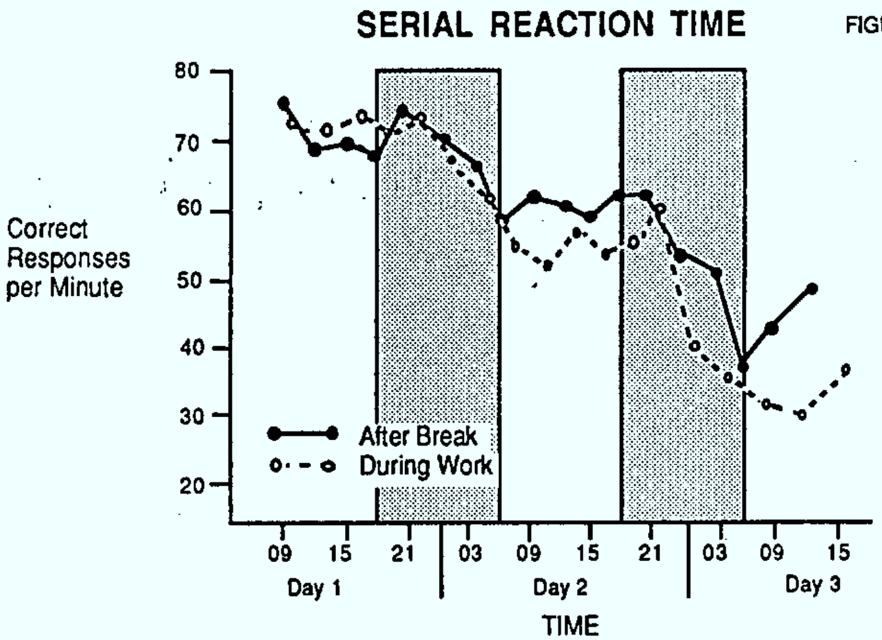

FIGURE 9. Reaction Time Performance Following Rest and Work

This figure shows differential changes in accurate responding as a function of whether subjects were tested following short rest breaks (solid line) or one hour of mental work (dotted line).

In summary, these studies were designed to address limitations in previous sustained operations research by providing subjects with a continuous, high-demand environment of tasks that were both cognitive in nature and that bore some similarity to command-post duties. The results demonstrated that 54 hours of sustained mental work produced great declines in performance and mood. Substantial decrements occurred following 18 hours of testing (reductions of greater than 30%), and generally unacceptable performance occurred following 42 hours of sustained wakefulness (greater than 60% reductions). These levels of degradation are greater than those found in past studies and probably reflect more accurately the decrements to be expected during sustained-intensive operations. As well, these data provided baseline information for further experiments in which attempts were made to counter the effects of sleep loss on performance.

3.5.2 Countermeasures: Unsuccessful Attempts

In order to ameliorate the degradations found in our basic sleep loss and continuous work paradigm, a number of countermeasure techniques have been investigated. Our first attempts to improve subjects' performance centred around physical conditioning and physical exercise. The first experiment compared individuals with high fitness levels to those of average fitness. Those findings suggested that when subjects were required to perform intense cognitive work during sleep loss, there was no difference in performance between subjects of varying fitness levels. That is, sleep loss effects were not dependent on level of physical fitness. This finding pertained to performance on cognitive tasks; performance on more physically demanding tasks may well be different.

A second experiment investigated the effect of "scheduled" physical exercise on performance during sleep loss. The experimental protocol was similar to the continuous mental work experiment except that half the subjects exercised every third hour by walking on a treadmill (at about 30% of their maximal oxygen uptake), while the other half watched television, played cards, read, or studied during the same time period. Both groups spent the other two hours performing the continuous cognitive tasks. No differences between the exercise and sedentary groups were observed on either subjective scales (see Figure 10) or objective measures of cognitive performance (see Figure 11). For a more complete account of this work see Angus, Heslegrave and Myles (1985).

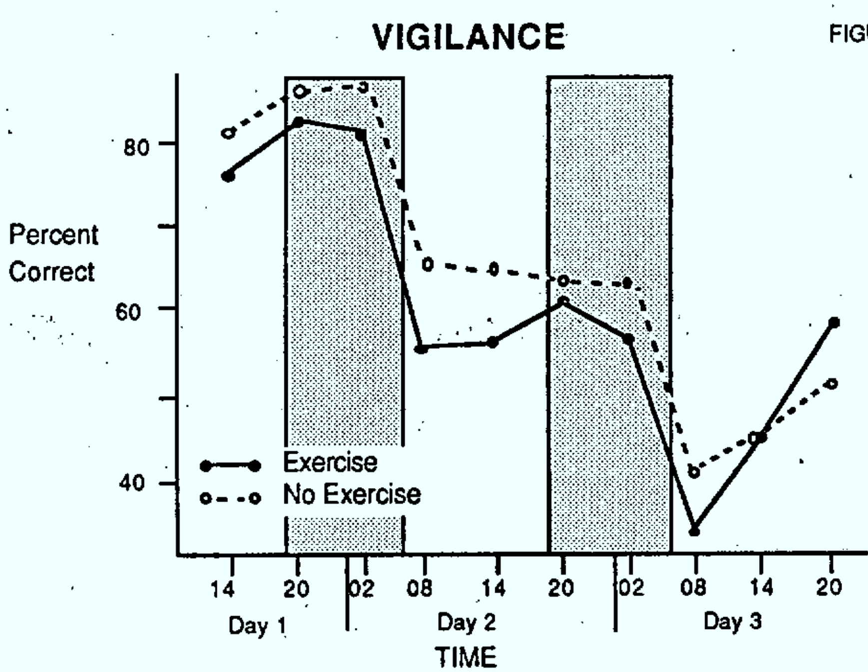

FIGURE 11. Scheduled Exercise Effects on Vigilance

Declines in percentages of correct detections in a 1-hour auditory vigilance task for both Exercise and No Exercise conditions. The subjects performed this task every six hours during the 60 hours of sleep loss.

A third experiment also involved exercise and continuous mental work over a 54-hour period of wakefulness. In this experiment subjects were given 30 minutes of hard physical exercise (at about 50% of their maximal oxygen uptake) in the middle of the second night of sleep loss (after 44 hours of wakefulness). Results typical of this exercise intervention are presented in Figures 12 and 13. It can be seen that there were no differences between subjects who exercised in the middle of the night and those who did not. It appears that a brief burst of exercise does not improve cognitive performance in sleep deprived people who have been expending intense mental effort.

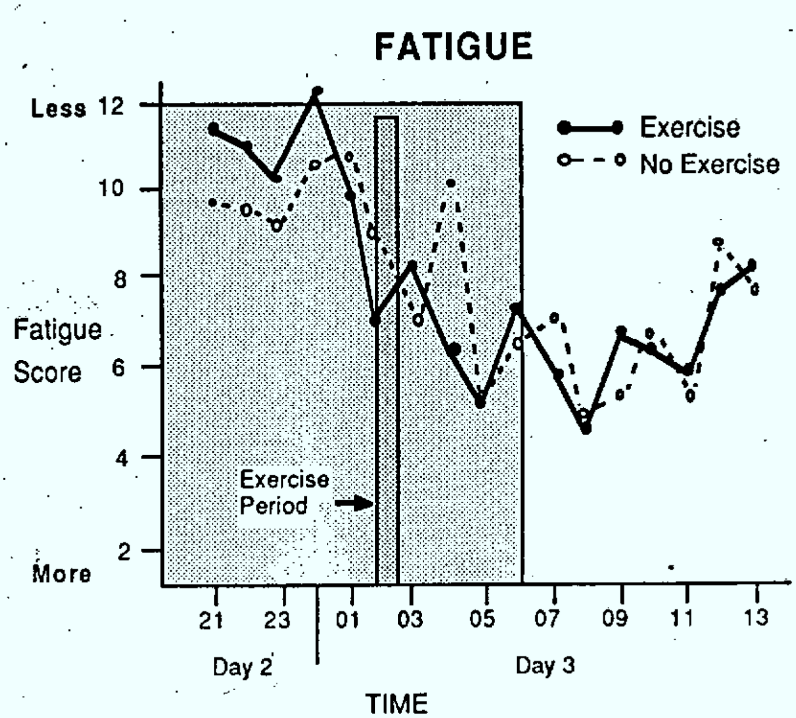

FIGURE 12. Acute Exercise Effects on Fatigue

Effect of a 30-minute period of physical exercise (at about 50% maximum oxygen uptake) after 44 hours of sleep loss and continuous mental work on subjects' self-reported fatigue (solid line). The results of a comparison group who did not exercise are also shown (dotted line). Data points are from scales completed hourly.

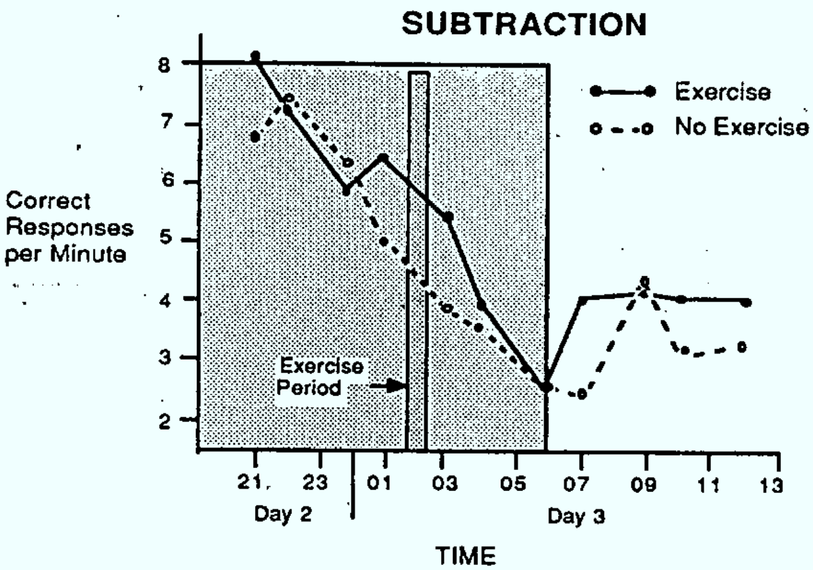

FIGURE 13. Acute Exercise Effects on Subtraction Performance

Effect of a 30-minute period of physical exercise (at about 50% maximum oxygen uptake) after 44 hours of sleep loss on subtraction task performance (solid line). The results from a group who did not exercise are also shown (dotted line). Each point plotted represents the mean of five 1-minute trials.

A fourth counterdegradation study was designed to determine if "rest" breaks are beneficial in reviving performance. Would a period of low cognitive workload (rest but not sleep) have a long-term benefit in preventing the large drop in performance observed in the previous continuous work experiments? For the first 27 hours of the experiment subjects performed the same high workload duties as in the experiments outlined previously. But, beginning at about 1200h following one night without sleep, the subjects' workload was reduced. This was done by requiring them to perform only the "Scales & Battery" package once every 1.5 hours for 12 hours (until about 2400h). In the times between task duties subjects read, watched movies, played games or rested; but they were not allowed to sleep.

The Fatigue Scale data (Figure 14) showed no differences between the group that received the period of low workload and a group that performed continuously. As well, this intervention did not assist in reducing the large decrements in performance during the second night of sleep loss; performance declined to levels expected of individuals not having the opportunity to "rest" during the previous daytime period. The negligible impact of this low daytime workload is also reflected in the results for the Logical Reasoning task(Figure 15). Thus, it appears that following one night of sleep loss and intensive cognitive work, a period of low workload serves neither to maintain nor to recuperate performance in the long term.

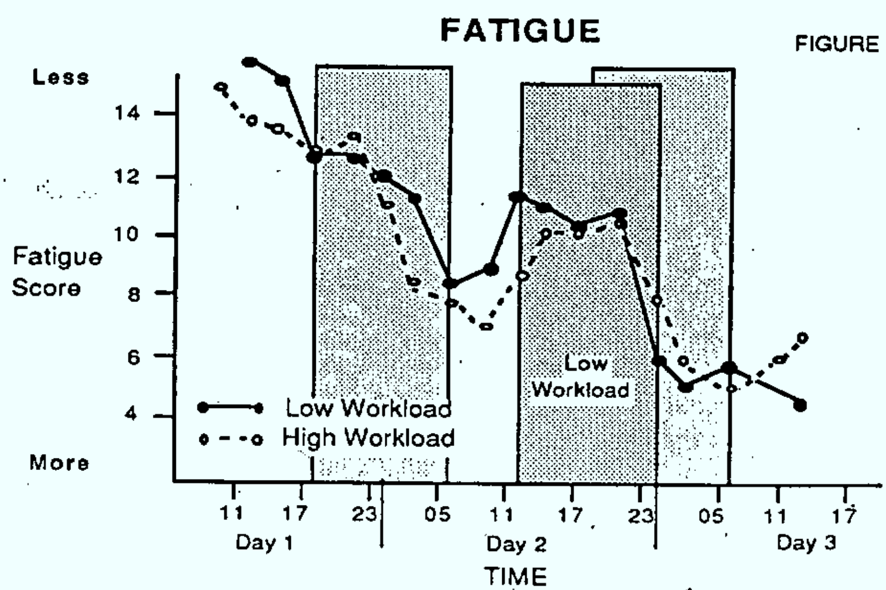

FIGURE 14. Low Workload Effects on Fatigue

Subjects' reported fatigue during sleep loss and continuous mental work which included a 12-hour period of "low workload". Results are contrasted with a group of subjects who experienced continuous work. (Data were not collected at equivalent points in the two experiments). Results are from trials occurring one hour into the work session (except during the low workload period).

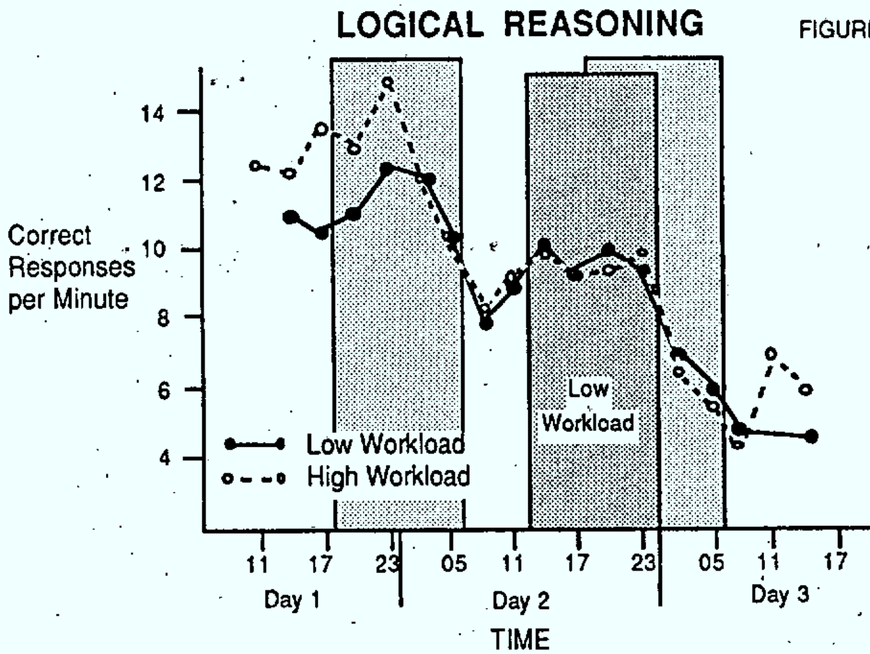

FIGURE 15. Low Workload Effects on Reasoning Performance

Subjects' correct response rate during a sleep loss and continuous mental work experiment which included a 12-hour period of "low workload". Results are contrasted with a group of subjects who experienced continuous work. (Data were not collected at equivalent times). Data were collected on a 2-minute version of the task from trials occurring one hour into work sessions (except during the low workload period).

To summarize these efforts, several experiments have been conducted in our continuous work paradigm. The results have been clear in indicating that sleep loss combined with intensive mental work leads to greater decrements in performance than have been reported in previous studies not emphasizing cognitive demands. To ameliorate this performance degradation, studies investigating the effects of physical fitness, physical exercise and altered workload demands have been completed. All of these interventions have been unsuccessful with respect to altering the effects of sleep loss.

3.5.3 Countermeasures: Naps

The most obvious intervention for counteracting the effects of sleep loss is sleep itself. As noted, in Section 2, there is controversy regarding how much sleep is necessary to maintain performance and whether it is better to take naps at certain times rather than at others. Using our continuous work paradigm, experiments are now underway to determine the ameliorative influences of 2-hour naps placed at various times during the circadian cycle.

The studies to be reported investigated the long-term performance "benefits" of naps. Can naps serve to maintain performance, that is, to prevent decrements in performance? Can naps be recuperative for degraded performance? We were also interested in determining the severity and duration of sleep inertia effects upon awakening. Two experiments investigating the maintenance and recuperative functions of nap sleep will be described and preliminary results presented.

3.5.3.1 Performance Maintenance

In the first nap experiment individuals worked continuously under high workload conditions for 40 hours and then received a 2-hour nap, from 2200h-2400h. Subjects did not expect the nap, nor were they informed of its duration. The nap was strategically placed prior to the second night of sleep loss. (The results of the continuous mental work experiments described in section 3.5.1 showed that performance fell to about 40% of baseline during the second night of sleep loss.) The aim of the present experiment was to determine if a nap taken prior to this expected decline in performance would prevent degradation. In short, would performance be maintained at the pre-nap level?

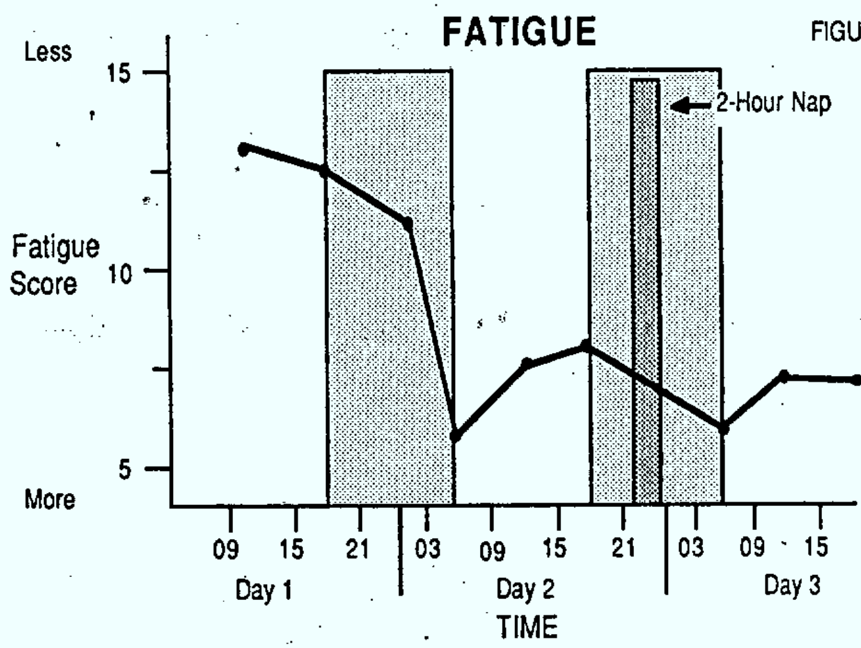

FIGURE 16. Early Nap Effects on Fatigue

Each data point represents the mean of six fatigue scores collected hourly. A nap occurred between 2200h-2400h after 40 hours of sleep loss.

As seen in the Fatigue Scale results shown in Figure 16, the 2200h-2400h nap had long-term beneficial effects. Other subjective and objective results revealed similar findings. For example, Figure 17 contrasts the data for the Logical Reasoning task from this experiment with those data from the continuous work (no nap) experiment. Performance following the nap remained at about the same level as that observed during the first night of sleep loss, that is, at about 70% of the levels observed at the beginning of the experiment. Without the nap, performance degraded to about 40% of baseline. Thus, a pre-midnight 2-hour nap prevented decrements that usually occur during and after the second night without sleep; performance was maintained at the pre-midnight level.

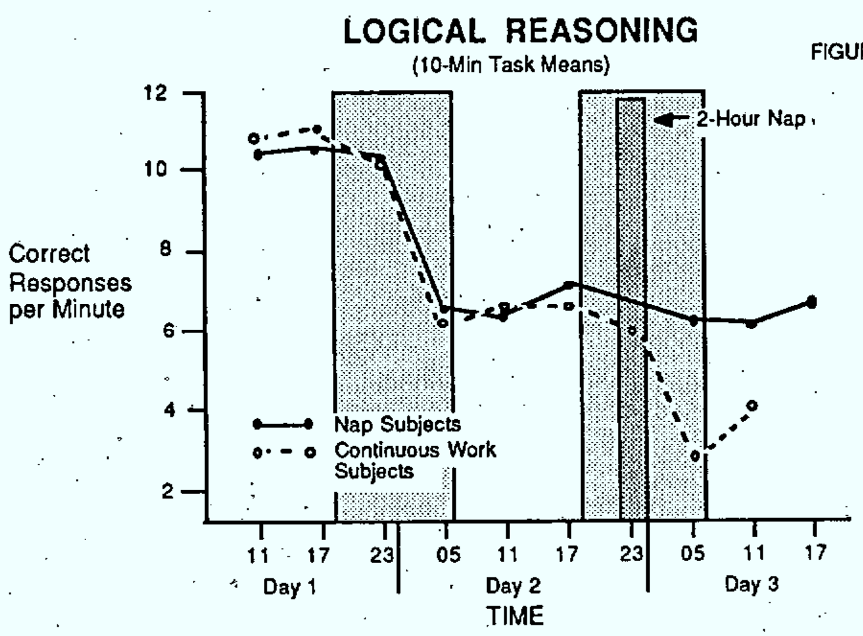

FIGURE 17. Early Nap Effects on Logical Reasoning Performance

Mean number of correct responses per minute for 10-minute trials of logical reasoning that occurred every six hours. Solid line represents a 60-hour sleep deprivation experiment that included a nap from 2200h-2400h after 40 hours of sleep loss. Dotted line represents results from the continuous work experiment.

Figure 18 illustrates the effect of sleep inertia using six 2-minute Reaction Time data points collected at two-hour intervals. Three were collected prior to the nap and three afterwards. The task was part of the Scales & Battery package which occurred immediately following rest breaks (and immediately after the nap). The results in the figure show that Reaction Time performance (assessed 5-10 min after awakening) was much more impaired after the nap than after a typical rest break. Whether this result is influenced by the amount of prior sleep loss or by circadian dependent changes in performance cannot be determined from this data. However, two hours later (0200h) performance returned to the pre-midnight level.

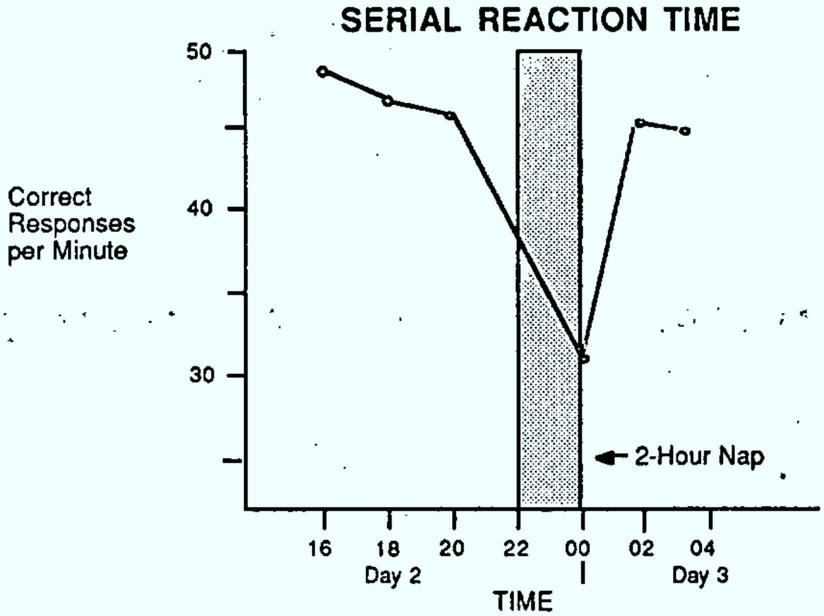

FIGURE 18. Early Nap Effects on Serial Reaction Time Performance

Mean number of correct responses on a 2-minute task. Data were collected "After Rest" breaks at three placements prior to a nap, immediately following the nap and following the next two rest breaks. The nap occurred between 2200h-2400h after 40 hours of sleep loss.

3.5.3.2 Performance Recuperation

The last study explored the "recuperative" power of a 2-hour nap. The nap (again unexpected) was placed in the "trough" (0400h-0600h) of the circadian cycle after about 46 hours of wakefulness. In other words, this placement is several hours after the beginning of the usual large decline in performance observed on the second night of sleep loss. The study represents an attempt to resolve the controversy regarding the performance benefits of early morning naps.

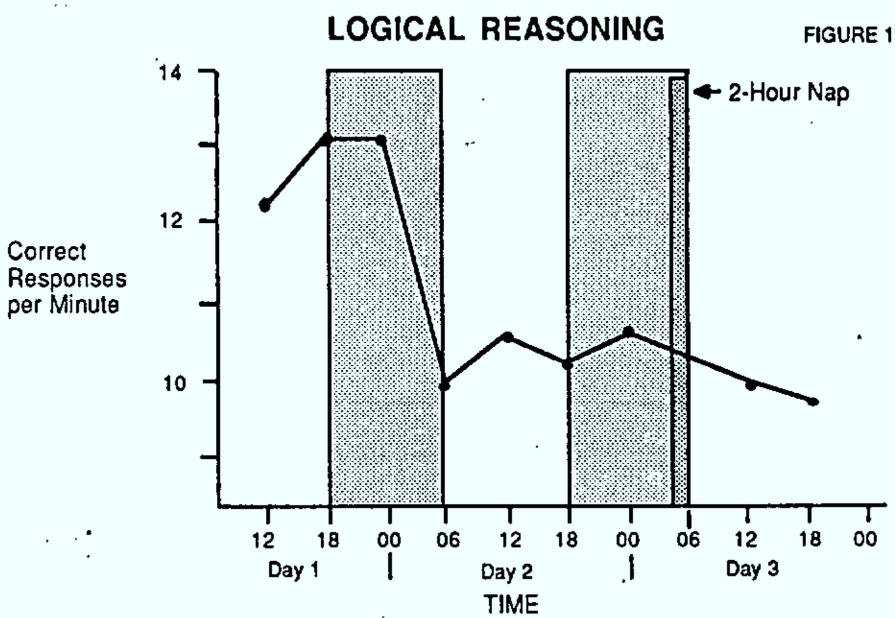

FIGURE 19. Late Nap Effects on Reasoning Performance

Mean number of correct responses per minute on the 10-minute logical reasoning task, which was given once every six hours during a 60-hour sleep deprivation experiment. A nap occurred between 0400h-0600h after 46 hours of sleep loss.

Preliminary results for the 10-minute Logical Reasoning task (Figure 19) illustrate the performance benefits from taking a nap at this time. Performance during the third day of the experiment was the same as that on the second day. Because testing on this task occurred only at 6-hour intervals and was eliminated during the nap period (0400h-0600h), it appears that the nap served to maintain performance between approximately midnight and noon. However, the 2-minute Logical Reasoning task embedded within the Scales & Battery package, which was collected every hour, clearly shows that after midnight the expected decline in performance occurred and the nap served to return performance to pre-midnight levels (Figure 20). Figure 20 also demonstrates that infrequent testing may lead to erroneous conclusions; clearly a detailed performance profile shows that the early morning nap was indeed recuperative while less frequent

testing (illustrated in Figure 19) may lead to the conclusion that the nap maintained performance. As was the case with the 2200h-2400h nap, Figure 20 demonstrates that performance was poor immediately following the nap and then showed recovery over the next two hours. These low performance levels immediately after the naps may be the result of sleep inertia (Naitoh, 1981).

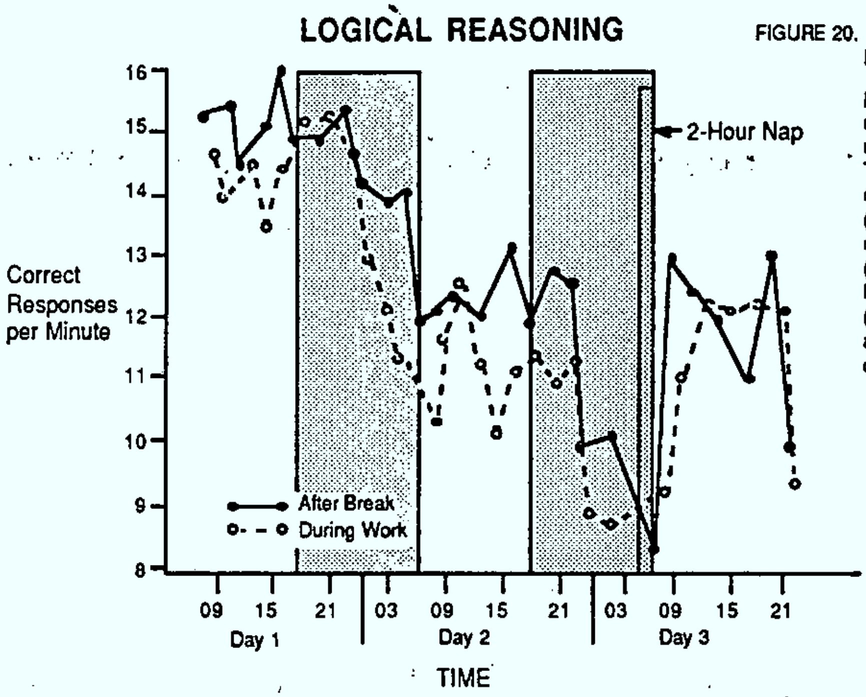

FIGURE 20. Late Nap Effects on Reasoning Following Rest and Work

Mean number of correct responses per minute on a logical reasoning task given every hour. The results are divided into trials occurring after a rest break (solid line) and trials occurring one hour into a work session (dotted line). Note the nap between 0400h-0600h (after 46 hours of sleep loss) and its recuperative effect on performance.

In summary, a nap taken at the low point in the circadian cycle, which followed the onset of performance deterioration, was shown to restore performance levels to those of the previous day. Thus, a 2-hour nap taken from 0400h-0600h does appear to provide some recuperation for cognitive performance.

4 DISCUSSION

Although the operational consequences of sleep deprivation have long been known, sleep logistics have not played a significant role in past or present military planning (Naitoh, 1983). One reason for this is that orderly civilian shift-work patterns are not applicable to the sustained-intensive battlefield. New work/rest guidelines based on the provision for short naps are required. While napping is generally accepted as a useful countermeasure for increasing alertness, there are several factors which must be understood before napping guidelines can be provided. In planning for sustained operations it is important to know the minimal amount of nap sleep required to maintain acceptable performance. As pointed out in the review of the experimental literature, however, the specification of how long one needs to nap may be complicated by the interaction of nap duration with the circadian cycle and the amount of prior wakefulness. Such complications have been difficult to explore because of methodological problems with the nap studies.

Even if the experimental design and measurement problems in the nap literature can be resolved, a more important concern is the generality of laboratory findings to battlefield conditions. For the most part, experimental subjects have lead relatively tranquil, low-demand existences. Although performance assessment may have been done at regular intervals, the level of performance required of subjects in past experiments did not demand sustained-intensive attention.

The present research programme was designed to address the limitations of previous work. In particular, an environment was developed in which many cognitive tests and measures were embedded in a long and intense duty cycle. Experiments conducted in this environment have indicated that the combination of sleep loss and intense mental work leads to greater decrements in performance than in studies not emphasizing cognitive demands: substantial decrements occur following 18 hours on duty (reductions of about 30%) with generally unacceptable performance occurring 24 hours later (Angus & Heslegrave,

1985; Heslegrave & Angus, 1985). Also, the efficacy of short duration measurement probes was demonstrated and applied in assessments of various countermeasures for sleep loss.

Some of our results suggest that certain countermeasures against sleep loss are not effective. Subjects' fitness levels, scheduled physical exercise, short bursts of strenuous physical exercise or periods of low workload do not have long term beneficial effects. However, short term ameliorative effects due to rest breaks are evident in all our studies. Performance and mood scores are consistently better immediately after breaks than an hour into the work sessions. The breaks seem to have a short-lasting positive influence on the subjects, and may provide a means by which temporary increases in performance can be effected during sustained operations. Additionally, both evening (2200h-2400h) and morning (0400h-0600h) naps were beneficial following 40 and 46 hours of sleep loss respectively. This implies, at least for these amounts of sleep loss, that the beneficial effects of naps may override circadian influences. When sleep loss is less severe, naps may provide a maintenance function; when sleep loss is more severe, naps may provide a recuperative function.

Overall, the results demonstrate the efficacy of our experimental paradigm: the continuous work environment amplifies sleep loss effects; the high frequency of testing yields finer and more sensitive results; and the military context in which the experiments are performed increases the validity of the results for battlefield situations. Efforts are now underway to increase the realism of our laboratory scenario further through the use of wargaming techniques.

Research to this point (ours as well as others) has emphasized the effects of sleep loss on <u>groups</u> of subjects. A further goal must be to extend these results to <u>individual</u> subjects. Our future research will emphasize real-time interventions, first in the laboratory and then in the field. For example, subjects may be given naps at times not dictated by a fixed experimental protocol, but at times dependent upon their individual performance. This will result in different subjects receiving naps at different times. The goal is to let subject parameters (in real time) control certain intervention aspects of the experiment.

To facilitate this approach, physiological data are also being collected in our experiments (e.g., ECG, EEG, respiration, and actigraphy). Although not mentioned in this paper, we have found that EEG activity tracks both performance and mood scores throughout sleep loss. In our most recent experiment, we included an "eyes-closed" relaxation period in the "Scales & Battery" package presented each hour. During this period, levels of drowsiness were measured subjectively by questionnaire and objectively with EEG (e.g. reduced alpha, and increased levels of theta and delta activity). For individual subjects, these EEG-defined drowsiness levels correlate highly with declining performance and mood scores (Pigeau, Heslegrave & Angus, 1987). Also, preliminary results from sleep EEG and ECG, both during the nap and during the recovery night sleep, suggest that electrophysiological indices (e.g., EEG delta activity, increased heart rate and decreased heart rate variability) may exist for determining the amount of sleep necessary to restore performance. Should these measures prove reliable, intervention research will have direct operational consequences. It may be possible, at the level of the individual, not only to specify the appropriate times for restorative naps, but also to estimate the optimal durations of these naps.

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